

3T Prostate Coils for 1H and 31P MR Spectroscopic Imaging

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INTRODUCTION

Magnetic resonance imaging (MRI) and magnetic resonance spectroscopic imaging (MRSI) provide information on the extent, location and characteristics of tumors that is invaluable in pre-treatment planning. At 1.5T MRSI has become a powerful clinical and research tool to characterize prostate cancers based on cellular metabolite levels and to detect response to therapy (1). High field, 3T ³¹P MRSI is promising due to the potential for increased SNR (2,3), making it possible to increase spatial resolution; which is essential in studying phosphate metabolism in the human prostate, which at 2T, though SNR limited, demonstrated the ability of detecting key metabolic differences in human prostate cancers (4). However, the lack of double tuned 3T prostate coils has prevented the use of this technique in clinical settings at 3T. In this study we developed two designs of dual tuned prostate coils: a concentric coplanar design and a concentric dual layer design.

METHODS

Based on prior experience, the optimal probe size of 3.9 inches by 1 inch was empirically derived to accommodate imaging the majority of the gland while maximizing patient comfort. Under these constraints we investigated two possible coil designs, leading to the concentric coplanar design and concentric dual layer design. A major concern in our implementation was the design of the housing for the concentric coils. A flexible, balloon-type coil, such as the commercially available type currently used for ¹H imaging, was impractical for our design due to loss of concentricity and spacing between the elements. Also we wanted to avoid susceptibility artifacts due to air-tissue interfaces at 3T. These concerns were resolved by constructing a rigid prostate probe from Delrin plastic. This material exhibits excellent chemical resistance, required for sterilization purposes, and electrical insulating properties, with a dielectric strength of 500 volts/mil and a volume resistivity of 10¹⁵ ohm-cm. It also has good mechanical properties with ultimate tensile strain of 60%, which is critical to eliminate brittle fractures and to produce a smooth well-tolerated probe. Each oval coil element, whether in coplanar or dual layer arrangement, was built from solid copper rod. Four capacitors were distributed symmetrically around each oval on the major and minor axes. This minimized the downfield shift of the resonance frequency during coil loading. In both designs, the ¹H portion of the coil was designed for use in receive only mode, with tuning and matching circuitry as well as an active PIN diode trap, for ¹H coil detuning during body coil transmit, built into the handle of the probe (Fig. 1). The ³¹P portion of the coils was designed for use in both transmit and receive modes. For the concentric coplanar design, the inner coil was tuned to 51.7 MHz (³¹P) while the outer coil was tuned to 127.7 MHz (¹H). This maximized the coverage of the ¹H coil while reducing the volume covered by the ³¹P coil, thus maximizing coil sensitivity. Since both coils in the dual layer design were identical in size, the ³¹P coil was placed nearest the prostate to maximize SNR for the less sensitive nuclei. This, however, distanced the proton coil an additional 3 mm from the prostate gland. In both designs, the objective was to maximize ³¹P sensitivity. The coils were tuned and matched to 50 ohms and decoupled from one another while loaded on the laboratory bench. No passive traps were used for either ³¹P or ¹H resonances in the coplanar coil; whereas passive traps were implemented for both ³¹P and ¹H resonances in the proton and phosphorus coils, respectively, in the dual layer prostate coil.

RESULTS

The unloaded and loaded bench Q measurements for both prototype coils are shown in Table 1. Note the minimal frequency shift between loaded and unloaded states achieved with distributed capacitance. Coil performance was evaluated by imaging a human volunteer. (Fig. 3a). During the same volunteer study non-localized phosphorus spectra was also acquired; these results are depicted in Figure 3b.



Figure 1. The internal circuitry of the concentric coplanar prostate coil.

Coil	P-31 Unloaded		P-31 Loaded	
	Q	Freq (MHz)	Q	Freq (MHz)
Coplanar	54	52	33	51.7
Dual Layer	43	51.9	35	51.7

Table 1. Coil characterization

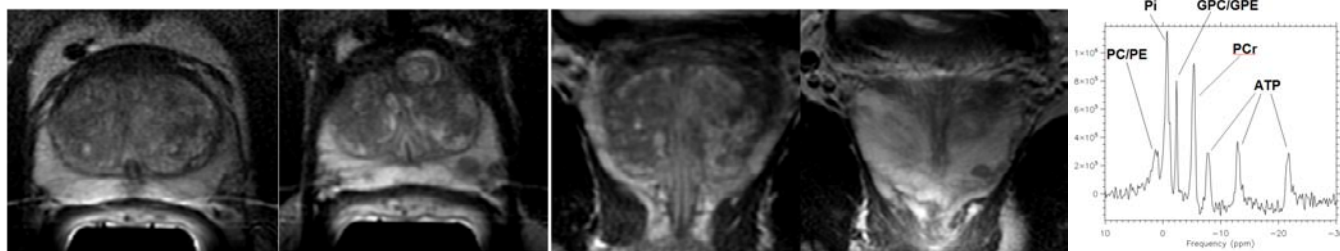


Figure 3. a) 3T MRI images of the human prostate acquired with coplanar endorectal coil. b) 3T MRSI from the human prostate acquired with coplanar coil

CONCLUSION

In this study, rigid endorectal 3T coils were developed with both ¹H and ³¹P elements to obtain high resolution MRI and MRSI of the human prostate. These new coils provided high sensitivity, adequate imaging coverage, satisfactory patient comfort and minimal susceptibility artifacts. Both designs performed well within their geometrical constraints. Studies are currently underway to define the relative SNR and spatial coverage for each of the designs for ¹H imaging, ¹H spectroscopy, and ³¹P spectroscopy.

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